2.5 SENSORS

Sensors are the system type in Suppressor, which enable a player to detect the presence of other player elements. Suppressor includes specific sensor models for electro-optic, infrared, radar, and radar warning receiver sensor types. Each of these sensor types is described below.

There are a few algorithms which apply to all sensor types in Suppressor. These are the ones which may cause a sensor to fail to detect targets due to terrain masking, horizon masking, field of view limits, as well as coarse range and altitude limits. Terrain masking is entirely dependent on the terrain model (if included in a simulation). Sensor field of view limits are user defined angular limits in azimuth and elevation from the sensor position. The coarse range and altitude limits are defined for each sensor type by the RNG-ALT-CAPABILITY data item.

2.5.1 Functional Element Design Requirements

The design requirements for the sensor functional element are:

a. Provide the capability for the user to define sensors that operate at any frequency within the electromagnetic spectrum.

b. Provide the capability for the user to define both active and passive sensor types.

c. The model will use the standard energy signal transmission and reflection equation to calculate the S/I received. The following user-defined parameters will be included for active and passive sensors:

    1. gain of the receiver type
    2. internal receiver type losses
    3. receiver frequency
    4. receiver type noise

    In addition, the model will provide the capability for the user to calibrate the sensor by defining the detection range of that sensor type for a one-square-meter target.

    For active sensors, the following user-defined transmitter type parameters will also be used in the S/I calculation:

    1. transmitter type peak power
    2. transmitter type gain
    3. internal loss for transmitter type

d. Provide the capability for the user to define an antenna gain table for each type of sensor transmitter and each type of receiver. The table will provide antenna gain values for frequency, azimuth, and elevation intervals arbitrarily defined by the user (frequency is optional). These values will define a step function; i.e., no interpolation will be performed. The vertical offset of the antenna may also be defined by the user.

e. For active sensor types, the model will provide the capability for the user to define MTI attenuation as a function of Doppler frequency intervals. In each sensing chance, the Doppler frequency will be calculated using the relative radial velocity of the sensor and the target and the following user-defined parameters:

   1. pulse repetition frequency of the sensor type
   2. frequency of the specific sensor

f. Suppressor will disallow detections for those sensing chances that do not meet the following user specifications:

   1. maximum and minimum radial speed limits
   2. symmetric azimuth limits
   3. maximum and minimum elevation limits
   4. elevation slew limits
   5. relative altitude limits for user-defined range intervals

g. The following data will automatically be obtained in a detection:

   1. time of detection
   2. frequency of signal detected
   3. IFF results if the user has specified IFF capability for this sensor type
   4. tracking results if detection occurs during track

   In addition, the model will accurately provide any of the following data for a detection if so instructed by the user:

   1. target altitude
   2. target azimuth
   3. target heading
   4. number of player elements
   5. target x,y location
   6. target speed
   7. type of element
   8. type of player

h. Provide the capability for the user to define a sensor as rotating or not rotating. Rotating sensors will be modeled as sweeping around in a plane parallel to the ground; at each sensing chance, targets always be modeled as in the main beam with respect to azimuth, but not necessarily with respect to elevation. Non-rotating sensor receivers are modeled as pointing as directly as possible at the target (subject to slew limits) for each sensor chance.

i. Provide the capability for a user to define sensor types that are search only, track only, or search and track. Search sensors will be used to provide information used in decision-making. Track sensors will be used in conjunction with weapon systems during an engagement. Users may specify whether or not each search and track sensor type can operate in both modes simultaneously (track-while-scan).

j. For each sensor type with tracking capabilities, the model will represent three modes of operation; acquisition (prior to lockon), track (after lockon, before firing), and guidance (after firing). The model will provide the capability for the user to define separate thresholds and separate probabilities of detection for pre- and post-lockon modes of tracking sensors.

k. For each sensor type with tracking capabilities, the model will provide a capability to implement the following user-defined time restrictions:

   1. delay from the decision to initiate an engagement until the first sensing chance is scheduled for the tracker.
   2. length of time the pre-lockon threshold must be used before switching to the post-lockon threshold.
   3. length of time a tracker can remain in coast mode (after losing lock) without causing enroute ordnance to abort.

l. For each sensor type with tracking capabilities, the model will limit the number of targets tracked simultaneously if the user has defined a maximum.

m. For each specific sensor receiver or transmitter in a scenario, the model will provide the capability for the user to define the following additional data:

   1. status: on, off (may be changed to on by decision-making capabilities), or non-op (nonoperational for the whole exercise or until a user-defined time for a status change). If the user does not specify a status, Suppressor will assume acquisition sensors are ON, and track sensors are OFF.
   2. any number of scheduled status changes (game time and new status)
   3. pointing direction at a specific platform or a specific geometric location or in a specific direction.

n. Provide a capability for the user to define an external sensor type and define the detection criteria.

2.5.2 Functional Element Design Approach

Design Element 5-1: Radio Frequency (RF) Sensors

The RF sensor functional elements are used to simulate sensor systems which operate at the RF signal range. In Suppressor these sensor types include radar sensor receivers and transmitters, as well as radar warning receiver sensors. RF sensors as well as all sensors in Suppressor may fail to detect targets due to terrain masking, horizon masking, field of view limits, as well as coarse range and altitude limits.

In Suppressor there are two sensor types that simulate RF sensors, RADAR and WARNING-RCVR. There are two separate modules to handle these two sensor types, OBSRDR is the radar sensor module and OBSLSN is the warning receiver sensor module. Sense events are scheduled at a user defined sensing rate between each sensor and each target within a reasonable range. When a sense event is simulated, the sensor type is determined and the module for the corresponding sensor type is invoked. Each sensor module, OBSRDR and OBSLSN, evaluates a signal-to-noise equation appropriate for that sensor and compares the signal-to-noise value with a user defined threshold. If the value is above the threshold, then the sense event is successful and target information is send to a mental event for processing. If the signal-to-noise value is below the threshold, then the sense event fails and no information is forwarded.

The primary target attribute used in the radar sensing algorithm is a RCS table in which RCS values are listed at various azimuth and elevation angles around the target. The RCS tables may also include dimensions for radar frequency, polarization, and target configuration. Target configuration is a newer Suppressor features which allows signature to vary with different configurations such as bays-open, bays-closed, wings-swept, etc.

The radar range equation as implemented in Subroutine OBSRDR is:

$$S = \frac{P_o \; D \; 10^{(R_{pc}/10)} \; (c/\nu)^2 \; 10^{[(L_t + L_r + L_o)/10]} \; 10^{[(G_r + G_t + A_{atm})/10]} \; \sigma \; A_{mti}}{(4\pi)^3 \; (R_{rt})^2 \; (R_{xt})^2}$$

$$P_n = P_j + 10^{(N_r/10)} + 10^{(P_{cl}/10)}$$

Detect if $(S/P_n) > 10^{(T/10)}$

Where:

A_{atm}	Atmospheric attenuation (dB) from TRANSMISSION-LOSS
A_{mti}	Attenuation from MTI-ATTENUATION
D	Transmitter DUTY-CYCLE
ν	Frequency of transmitter XMIT-FREQ (hertz)
G_r	Receiver gain (dB) from receiver ANTENNA-PATTERN
G_t	Transmitter gain (dB) from transmitter ANTENNA-PATTERN
L_o	Receiver OPERATING-LOSSES (dB) from DETECTION-SENSITIVITIES
L_r	Receiver INTERNAL-LOSSES (dB) from DETECTION-SENSITIVITIES
L_t	Transmitter loss, INTERNAL-LOSS (dB)
N_r	RECEIVER-NOISE (dB) from DETECTION-SENSITIVITIES
P_{cl}	Power (dB) from receiver CLUTTER-TABLE
P_j	Sum of power from noise jammers
P_n	Total noise
P_o	Transmitter PEAK-POWER-OUTPUT (watts)
P_p	Power from pulse jammers
R_{pc}	Transmitter PULSE-COMPRESSION-RATIO (dB)
R_{rt}	Range (meters) between receiver and target
R_{xt}	Range (meters) between transmitter and target
S	Total signal power
T	SENSING-THRESHOLD (dB) or POST-LOCKON-THRESHOLD (dB) from DETECTION-SENSITIVITIES
c	Velocity of light (2.99776E8 meters/sec)
σ	Radar cross section (m^2) of target from RCS-TABLE

In Suppressor, a warning receiver is a passive RF sensor. It can detect emissions from radar or communications transmitters. The signal-to-noise equation used for sense events when the sensor is a warning receiver is implemented in Subroutine OBSRDR using this algorithm:

$$K = N_r + T - G_r + 10Log(4\pi/c)^2 - L_r + 20LogR$$

$$P = 10LogP_t + L_t - 20Log\nu + A_{atm}$$

Mainbeam detect if: $(P + G_{tm}) > K$
Backlobe detect if: $(P + G_{tb}) > K$

Where:

A_{atm}	Atmospheric attenuation (dB) from TRANSMISSION-LOSS
c	Speed of light
ν	Frequency (hertz) of target emitter, from XMIT-FREQ or SDB FREQ:
G_r	Gain from the warning receiver ANTENNA-PATTERN (dB)
G_{tm}	Gain from the target emitter ANTENNA-PATTERN (dB)
G_{tb}	Backlobe gain from the target emitter, RWR-BACKLOBE-GAIN (dB)
L_r	Receiver INTERNAL-LOSSES (dB) from DETECTION-SENSITIVITIES
L_t	Transmitter INTERNAL-LOSSES (dB)
N_r	RECEIVER-NOISE (dB) of the warning receiver
P_t	PEAK-POWER-OUTPUT of target emitter (watts)
R	3-D range between receiver and target emitter (meters)
T	SENSING-THRESHOLD (dB) of the warning receiver from DETECTION-SENSITIVITIES

Design Element 5-2: IR Sensors

Individual sense events for infrared sensors and their targets are scheduled at the user specified sensing rate for all targets within a user-defined range of the infrared sensor. If the conditions between the sensor and target pass all of the generic sensing conditions including masking, then the infrared specific sensing algorithm is invoked. The following steps are the infrared sensing algorithm as implemented in Suppressor:

a. Compute the apparent intensity of the target

$$I_{tgt} = (2/3\pi^2) * (3\pi/8) * A_{tgt} * R_{tgt} * E_{sun} + I_{intens}$$

b. Compute the apparent intensity of the background

$$I_{back} = B_{back} * A_{tgt}$$

c. Compute the field of view for the target

$$\Omega_{tgt} = A_{tgt} / R^2$$

d. Determine the fraction of the field of view covered by the target

$$F_{fov} = MIN\,[(\Omega_{fov}/\Omega_{tgt}), 1.0]$$

e. Compute signal-to-noise ratio

$$R_{sn} = F_{fov} \frac{(I_{tgt} - I_{back}) \quad A_{atm}}{R^2 \quad N_{ei}}$$

f. Compare with SENSING-THRESHOLD

Detect if $R_{sn} > T$

Where:

A_{atm}	Atmospheric attenuation (converted from dB) from TRANSMISSION-LOSS table
A_{tgt}	Target presented area (m^2) from OPT-CS
B_{back}	Atmospheric BACKGROUND-RADIANCE (watts/steradian/m2)
E_{sun}	SOLAR-IRRADIANCE of the sun (watts/square meter)
F_{fov}	Fraction of pixel field of view covered by the target
I_{back}	Apparent intensity of the background (watts/steradian)
I_{intens}	Target infrared intensity from IR-INTENSITY (watts/steradian)
I_{tgt}	Apparent intensity of the target (watts/steradian)
N_{ei}	Noise equivalent irradiance (w/m^2) from RECEIVER-NOISE in DETECTION-SENSITIVITIES
R	Range between the sensor and target (meters)
R_{sn}	Signal-to-noise ratio
R_{tgt}	Reflectance of the target from TGT-REFLECTIVITY
T	SENSING-THRESHOLD from DETECTION-SENSITIVITIES
Ω_{sn}	Field of view for the sensor from PIXEL-FIELD-OF-VIEW
Ω_{tgt}	Field of view presented by the target

Design Element 5-3: Electro-optical (EO) Sensors

The optical sensing algorithm implemented in three steps:

a. Compute the contrast of the target with its background.

$$C_{tgt} = C_i \quad A_{atm} \frac{B_{back}}{(B_{back} \quad A_{atm} + B_{path})}$$

b. Compute the target size.

$$\Omega_{tgt} = A_{tgt} / R^2$$

c. Compute the conditional probabilities for every glimpse (3 per second) since the last sense event as specified by the sensing rate of the optical sensor.

$$P_{St} = (1-G_s) * P_{St-1} + (1/N_r) * (1-G_r) * P_{Rt-1}$$

$$P_{Tt} = G_t * P_{Tt-1} + G_r * P_{Rt-1} + G_s * P_{St-1}$$

$$P_{Rt} = 1 - P_{Tt} - P_{St}$$

Detect if $P_{Tt} > T$

Where:

A_{atm}	Atmospheric attenuation (dB) from TRANSMISSION-LOSS
A_{tgt}	Target presented area (m^2) from OPT-CS
B_{back}	Atmospheric BACKGROUND-RADIANCE (watts/steradian/m^2)
B_{path}	Atmospheric PATH-RADIANCE (watts/steradian/m^2)
C_i	INHERENT-CONTRASR for the target
C_{tgt}	Computed contrast for the target and its background
G_r	Single glimpse probability of re-acquisition from REACQ-GLIMPSE-PROB
G_s	Single glimpse probability of search from SEARCH-GLIMPSE-PROB
G_t	Single glimpse probability of track from TRACK-GLIMPSE-PROB
N_r	Number of glimpses possible during REACQUISITION-TIME
P_{Rt}	Probability of re-acquisition at time t
P_{St}	Probability of search at time t
P_{Tt}	Probability of track at time t
R	Range between the sensor and target (meters)
T	SENSING-THRESHOLD from DETECTION-SENSITIVITIES
Ω_{tgt}	Target size

The primary target attributes used in the optical sensing algorithm are an optical cross section (presented area) table and a single value for the inherent contrast of the target with its background. In the optical cross section table, presented area values are listed at various azimuth and elevation angles around the target. The optical cross section table may also include a dimension for target configuration. Target configuration is a newer Suppressor feature which allows signature to vary with different configurations such as bays-open, bays-closed, wings-swept, etc.

Design Element 5-4: External Sensors

Suppressor includes a feature which allows users to easily code and insert their own unique sensor type. These external sensors as well as all sensors in Suppressor may fail to detect targets due to terrain masking, horizon masking, field of view limits, as well as coarse range and altitude limits. In addition, the external sensor may include any attributes specified for it in the EXTERN module.

The module which controls all Suppressor sense events includes code to identify and process sense event to be performed by an external sensor. There is one module, EXTERN.F, included in the Suppressor code which is invoked when an external sensor is being used. Users building their own sensor model can easily write their own version of EXTERN.F and compile it into a Suppressor simulation.

2.5.3 Functional Element Software Design

RF Sensor Module Design

The radar sensing algorithm design for Subroutine OBSRDR is:

```
*begin logic to perform radar sensor calculations:
   *when within sensing limits:
      *look up time of sense chance;
      *look up target position pointer;
      *look up receiver position pointer;
      *look up receiver data pointers;
      *calculate range from sensor to target;
      *invoke logic to calculate jammer signals;
      *calculate square of range from xmtr to target;
      *calculate range to target;
      *look up peak transmitter power out;
      *adjust power for pulse doppler, pulse compression
      *invoke logic to target signal calculations;
      *when clutter is modeled:
         *perform lookup to determine clutter power;
         *when terrain data:
            *invoke logic to get terrain altitude under target;
         *end of test for terrain.
      *end of test for clutter.
      *look up internal receiver noise;
      *evaluate visibility for target vs clutter plus noise;
      *calculate total noise level;
      *when pulse jamming is present:
         *set interference to pulse jamming level;
         *use pulse jamming detection threshold;
      *but, when noise predominates:
         *set interference to total noise level;
         *determine threshold based on noise jamming level;
      *end of test for jamming modulation.
      *evaluate visibility for target vs interference;
      *when target is visible over clutter+noise and jamming:
         *target is visible;
         *when operational-probability-of-detection available:
            *determine current radar operator workload;
               *add other targets being tracked to workload;
            *find interval in prob-detect data for workload;
            *find interval in prob-detect data for s/n level;
            *find perception block for target, if it exists;
            *when current target has an established track:
               *use cued probability of detection;
            *but, when current target has external source:
               *use external-cue probability of detection;
            *otherwise current target is new:
               *use uncued probability of detection;
            *end of type of cue determination.
            *when draw is above the probability-of-detection:
               *set result to failed sense event, clear jam flag;
            *end of test for draw above probability-of-detection.
         *end of test for operational-probability-of-detection.
      *end of test for target visibility.
      *when jammer is visible over internal noise:
         *jamming is present;
```

```
        *end of test for target visibility and jammer effectiveness.
        *when operator thinks the radar is being jammed:
           *set operator thinks the radar is being jammed flag;
           *when there are alternate frequencies:
              *when not currently changing frequency:
                 *get next available frequency;
                 *schedule change frequency event;
                 *write out "starts to change freq" message;
              *end of test if not currently changing frequency.
           *end of test for alternate frequencies.
        *otherwise, operator thinks the radar is not jammed:
           *clear operator thinks the radar is being jammed flag;
        *end of test if operator thinks the radar is jammed.
        *store flag and time operator thinks the radar is jammed;
        *when jamming interfered:
           *write is-jammed-(explicitly) message;
        *end of test if jamming interfered.
     *end of test for within sensing limits.
  *end of logic for OBSRDR.
```

The warning receiver sensing algorithm design for Subroutine OBSLSN is:

```
  *begin logic for emitter receiver calculations:
     *when target within sensing limits:
        *initialize output pointer and flags;
        *look up antenna pointing info and pattern for receiver;
        *calculate constant part of one-way radio equation;
        *look up or initialize values for candidate groups;
        *initialize upper and lower frequency limits for receiver;
        *look up mainbeam/backlobe detection criteria;
        *loop, while target groups left to be checked:
           *loop, while systems left to be checked:
              *when sensor found on interaction table:
                 *set values used to determine transmission losses;
                 *when system is a comm transmitter:
                    *when the transmitter is operating:
                       *determine the status of the transmitter;
                       *when the transmitter is transmitting:
                          *look up frequency, power, loss, net type;
                          *determine transmission loss;
                          *set mainbeam option (default)
                       *end of check for continuous transmission mode,
                       * or transmitter is transmitting.
                    *end of check for the transmitter is operating.
                 *but, when an emitting sensor transmitter:
                    *look up frequency, power, losses;
                    *determine transmission loss;
                    *determine detection options;
                    *invoke emitter pointing if mainbeam desired;
                    *set default calculations if no criteria chosen;
                 *end of test for comm or sensor transmitter.
                 *when calculations needed and frequency limits:
                    *check for emissions within limits;
                 *end of test for calculations and limits.
                 *when calculations should be done:
                    *initialize flags to no detection;
                    *process comm or mainbeam calc if required;
                    *process backlobe calculation if required;
                    *cumulate detection results for target cluster;
                    *when enough signal exists for detection:
                       *allocate emitter results and add to list;
                       *store the sensor type code, sense time, id;
                    *end of test for signal level.
                 *end of test for calculations to be performed.
```

```
            *end of test for interaction table.
         *end of loop for systems.
         *when internal success flag was set:
            *increment counter and add group id to list;
         *end of test for successful sensing.
      *end of loop for target groups.
      *when any target groups sensed:
         *when group list was revised:
            *allocate new perceived group list and copy the data;
            *recycle temporary perceived group list;
         *end of test for revised group list.
      *otherwise, no target groups seen:
         *store saved number of groups;
      *end of test for target groups sensed.
      *set mainbeam/backlobe results if applicable;
   *end of test for within sensing limits.
```

IR Sensor Module Design

Infrared sensors are passive sensors which detect the heat from a target contrasted with its background. Infrared sensors in Suppressor are identified using the keyword INFRARED in the SNR-CHARACTERISTICS data item. Infrared as well as all sensors in Suppressor may fail to detect targets due to terrain masking, horizon masking, field of view limits, as well as coarse range and altitude limits. The detection algorithm which applies only to infrared sensors in implemented in Subroutine OBSIR.

The infrared sensing algorithm design for Subroutine OBSIR is:

```
*begin logic to perform infrared sensor calculations:
   *when within sensing limits:
      *look up target, sensor position pointers;
      *look up receiver data pointers;
      *calculate range from sensor to target;
      *look up transmission loss;
      *calculate signal-to-noise ratio;
      *when target angle at sensor exceeds field of view:
         *adjust signal-to-noise ratio;
      *end of test for pixel field of view.
      *evaluate visibility for target vs interference;
   *end of test for within sensing limits.
*end of logic for OBSIR.
```

EO Sensor Module Design

EO sensors are passive sensors which enable their operator to detect targets from an image of the target area. Electro-optical sensors are simulated in Suppressor using sensor receivers identified as OPTICAL in the SNR-CHARACTERISTICS data item. Optical as well as all sensors in Suppressor may fail to detect targets due to terrain masking, horizon masking, field of view limits, as well as coarse range and altitude limits. The detection algorithm which applies only to optical sensors in implemented in Subroutine OBSOPT.

This is the optical sensing algorithm implemented in Subroutine OBSOPT:

```
*begin logic to perform optical sensor calculations:
   *look up pointer to sensor/target buffer, receiver data;
   *when within sensing limits:
      *look up target, sensor position pointers;
      *look up receiver data pointers;
      *calculate range from sensor to target;
      *look up transmission loss;
```

```
        *look up background and path radiance;
        *compute background radiance at the sensor;
        *compute solid angle of target at sensor;
        *when background radiance is zero:
           *loop, for search, reacq, and track glimpse tables:
              *get highest contrast dimension value from tables;
           *end of loop for tables.
        *but, when background radiance not zero:
           *compute target contrast at the sensor;
        *end of test for background radiance.
        *look up single glimpse prob for search, reacq, track;
     *but, when target not within limits:
        *set single glimpse probabilities to zero;
     *end of test for within limits.
     *look up cumulative detection probabilities for target;
     *determine number of glimpses in reacquisition interval;
     *initialize sensing rate to acquisition mode;
     *adjust rate depending on track and fire conditions;
     *compute sensing cycle time;
     *loop, for number of glimpses in sensing interval:
        *calculate probability of search, reacq, track;
     *end of loop for number of glimpses.
     *store cumulative probabilities for next sense chance;
     *evaluate visibility for target;
  *end of logic for OBSOPT.
```

External Sensor Module Design

Subroutine EXTERN as distributed with Suppressor has no embedded sensing code. Users who write their own external sensor can store their results in this array:

```
SDATA(1)     = detected x-coordinate of target (meters)
SDATA(2)     = detected y-coordinate of target (meters)
SDATA(3)     = detected z-coordinate of target (meters)
SDATA(4)     = track confidence factor [0.0 - 0.9]
SDATA(5)     = detected target speed (meters/second)
SDATA(6)     = detected target heading (radians)
SDATA(7)     = detected target azimuth (radians)
SDATA(8)     = track data decay factor
SDATA(9)     = identification friend/foe (iff) data decay factor
SDATA(10)    = target type data decay factor
SDATA(11)    = not used
ISDATA(12)   = iff (1=friend, 2=hostile, 6=unknown, 7=neutral)
SDATA(13)    = iff confidence factor [0.0 - 0.9]
ISDATA(14)   = target type code
SDATA(15)    = target type data confidence factor  [0.0 - 0.9]
ISDATA(16)   = detect flag (1=not successful, 5=successful)
```

Suppressor will read and process these data from an external sensor, merging the data with other sources of information.

2.5.4 Assumptions and Limitations

- Acoustic sensors are not modeled.
- Only one value can be specified for the inherent contrast. This implies that one sensor looking up at the target with a sky background will have the same contrast as the sensor looking down with terrain or water as the background.

- Beamwidth, target size, and range are not considered when determining the number of targets sensed. Two or more targets in tight formation are always distinguished if the S/N is adequate.

2.5.5 Known Problems or Anomalies

None.